Formation and Characterization of Strained $Si_{1-x}Ge_x$ Films Epitaxially Grown on Si(100) by Low-Energy ECR Ar plasma CVD without Substrate Heating

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1. Introduction

To obtain high-quality and high-Ge-fraction strained $Si_{1-x}Ge_x$ films on Si(100), lower process temperature during $Si_{1-x}Ge_x$ deposition is necessary for quantum-effect nano heterostructures of group IV semiconductors [1]. Plasma CVD process is one of the candidates for low-temperature epitaxial growth [2]. In this work, formation and characterization of $Si_{1-x}Ge_x$ films epitaxially grown on Si(100) by using low-energy electron-cyclotron-resonance (ECR) Ar plasma CVD without substrate heating were investigated.

2. Experimental

$Si_{1-x}Ge_x$ films on Si(100) were formed by SiH_4 and GeH_4 reaction under low-energy Ar plasma irradiation with the microwave power of 200 W without substrate heating (**Fig. 1**). Ar partial pressure was 2.1 Pa. Typical partial pressures of SiH_4 and GeH_4 were (0.6-3)x10^{-4} Pa and (1.5-9)x10^{-4} Pa, respectively. Substrate temperature was suppressed below 50 °C during plasma exposure even for a few hundred seconds. Substrates used were partially SiO_2 covered p-type Si(100) wafers, and were treated in a few % diluted HF solution to remove the native oxide and rinsed with deionized water just before loading into the reactor. To minimize air contamination into the reactor chamber, wafer loading and unloading were performed through a N_2 purged transfer chamber combined with a gate valve. Ge fraction was evaluated by X-ray photoelectron spectroscopy (XPS). Crystallinity, surface roughness and lattice constant of the films were evaluated by reflection high energy electron diffraction (RHEED), atomic force microscope (AFM) and X-ray diffraction (XRD).

3. Results and discussion

It has been clearly shown that Ge fraction of the $Si_{1-x}Ge_x$ thin film is in good agreement with normalized GeH_4 partial pressure $P_{GeH4}/(P_{GeH4}+P_{SiH4})$ (**Fig. 2**). From RHEED patterns of deposited $Si_{1-x}Ge_x$ films on Si(100), it has been also found that epitaxial growth can be realized for lower Ge fraction below 0.5 and the crystallinity tends to be degraded by increasing the Ge fraction. Additionally, it is found that the crystallinity for $Si_{0.50}Ge_{0.50}$ can be improved effectively by increasing Ar purge time at reactor prior to deposition up to a few tens min. As a result, smooth surface for a 12 nm-thick epitaxial $Si_{0.50}Ge_{0.50}$ film on Si(100) can be confirmed and its vertical lattice constant (about 0.566 nm) obtained by XRD shows that the lattice is highly strained compared to a case of strain-relaxed $Si_{0.50}Ge_{0.50}$ (about 0.554 nm) (**Fig. 3**). This indicates that our ECR plasma CVD process has a potential to achieve highly strained heterostructure without strain relaxation and thermal interdiffusion at the heterointerface which are necessary for quantum-effect devices. Further investigations on electrical properties and so on are important to establish quantum heterointegration process by low-energy plasma CVD.

Acknowledgments

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References

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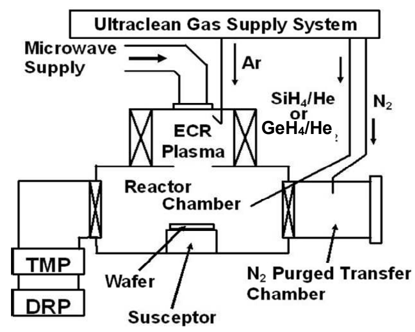

Fig. 1. Schematic of ECR Ar plasma CVD system.

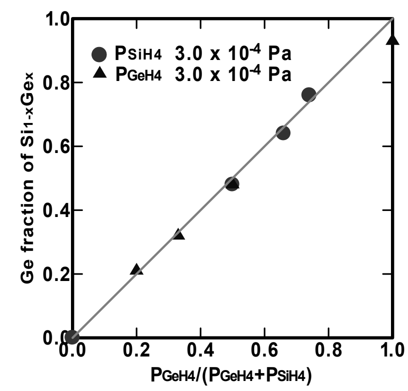

Fig. 2. Relationship between normalized GeH_4 partial pressure $P_{GeH4}/(P_{GeH4}+P_{SiH4})$ and Ge fraction of $Si_{1-x}Ge_x$ thin film. Here, Ge fraction was evaluated by XPS.

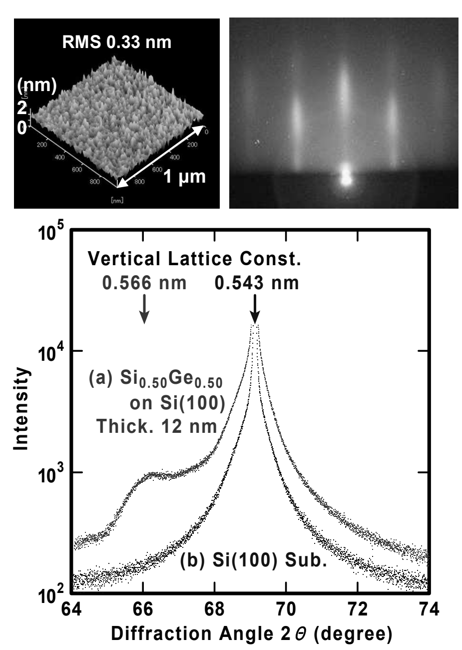

Fig. 3. AFM image, RHEED pattern and XRD curve of a 12 nm-thick $Si_{0.50}Ge_{0.50}$ film on Si(100). Deposition time was 5 min.